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A method for identifying closed areas and defining masks in a digital image

The present invention relates to the processing of images in general, and in particular to systems for processing digital images.

The invention has been developed with particular reference to a method for identifying closed areas and defining corresponding masking zones with respect to the contours of objects depicted in a complex image, for instance the image of a building or of the interior of furnished premises.

An increasing number of applications require the masking of specific zones of a digital image for subsequent processing, for instance in order to cut out specific images from the image, or to modify the colour or the shape of particular objects, leaving the remainder of the image unchanged, or vice versa. A widely known system is the "croma-key" system. This system, of analog type, makes it possible to remove those areas having a predetermined colour from an image and is often used to superimpose the image of a person on a background selected at will.

The croma-key system and its drawbacks, and a system for remedying these drawbacks with reference to the processing of a digital image, are set out in detail in US Patent US-A-5 469 536. This patent discloses a method of image processing with a masking facility that remedies the problems of the conventional croma-key system and makes it possible to define, from the digital image of a person on a substantially uniform background, the contour separating the person and this background, so as to be able to remove those portions of the image, i.e. the background itself, located outside the contour. In this way, the resulting image can be superimposed on a background of different type previously input and stored in digital form in the memory of an electronic processor. The method by which the contour is identified consists in organising the points of the digital image in successive rows and analysing the colour of these points in succession until, for each line, there is a difference between the chromatic hue values of two adjacent points that is greater than a predetermined threshold. One of the two points at

which such a difference in chromatic hue is detected is therefore defined as belonging to the background and the other to the image to be masked. The method takes place simultaneously for the right-hand and left-hand side of the image.

The method disclosed in the Patent US-A-5 469 536 has the drawback that the background of the digital image necessarily has to be of a substantially uniform colour. Moreover, this system can locate only the contour of convex images, for instance the image of a person's face. The method is unable to locate the contour of concave objects that have zones with recesses, niches or hollows. The method is unable, moreover, correctly to detect the contours of a plurality of objects depicted in an image, when these are partially superimposed or have their respective contours entirely enclosed within one another. A further drawback lies in the fact that the method is unable to detect any holes or cut-outs in the image to be masked which, for instance, allow the background to be seen or to show through zones contained within the outermost contour of an object.

Various solutions have been proposed to remedy the above-mentioned problems, which require varying degrees of interaction with a user, for instance roughly to define a vicinity of the image in which to search for the contour of a figure, or to define, in a limited zone of the image, the difference between chromatic hues representative of the background and the figure respectively. An example of these user-guided masking procedures is the masking product known by the trade name Mask Pro marketed by the Extensis Corporation as described as the Internet address http://www.extensis.com/.

Although the above-mentioned systems make it possible to achieve precise masking results, they are intended, however, for professional use and require substantial experience of use, in addition to the fact that the identification of closed areas in a complex image and their masking is generally time-consuming.

Among others, an application of particular interest of masking systems is in the sector of so-called tintometric systems, in which a metering machine supplies

predetermined quantities of one or more colouring agents concentrated within a container containing a base product of uniform colour, in most cases white or transparent, in order to obtain a final paint of the desired colour. In this sector, it is increasingly necessary to be able to provide potential customers with an advance idea of the result that could be obtained with the final paint when it is for instance applied to objects or types of furnishings, or when it is used to paint the walls of a room or even the outside of a building. Techniques are known in this respect for displaying the final colour of a paint, on the basis of parameters identifying this paint, on the screen of a electronic processor.

Merely displaying the final paint colour in advance is often not enough, however, to give an idea of the final result and it is becoming increasingly necessary to show potential customers what effect this paint will have when applied to a particular object. The object of the present invention is to provide a processing system for a digital image that makes it possible rapidly and simply to identify the contours of figures within this image, in order to be able to mask these figures independently from one another and from the surrounding background zones. A further object of the invention is to provide a system of the above-mentioned type that can work in combination with a tintometric system, and in particular with a colouring agent metering device, in order to provide as output a paint of a desired colour. The possibility of using, for the application of the system of the present invention, the same electronic processor adapted to control this colouring agent metering machine, is particularly useful in this respect.

In order to achieve these objects, the invention relates to the method as set out in the accompanying claims.

As a result of the present invention, potential customers may for instance go to a sales point that uses a tintometric system, with an image depicting the object, room or building whose colour they wish to change. If this image is not already in digital format, it can be converted into this format, for instance using a scanner, and input into an electronic processor, preferably the same processor used to control the paint metering machine. Once the image has been input, the system of

the present invention identifies the contours of closed areas within the image, corresponding to the contours of objects depicted therein. The customer can then use an inputting system, for instance a keyboard, a mouse, a joystick or the like, to interact with specific figures selected and masked within this image and displayed on a video screen, or with the areas external thereto, for instance in order to modify the colour of the walls of a room without changing the colour of the furnishings visible in the image.

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Further characteristic features and advantages of the present invention are set out in the following description of a preferred embodiment thereof, given by way of non-limiting example, and made with reference to the accompanying drawings, in which:

Fig. 1 is an example of an image converted into grey tones for the application of the method of the present invention;

Fig. 2 is a representation of the image of Fig. 1, at the end of processing by an edge-detection algorithm and of a possible border closure cycle,

Fig. 3 is a representation of the image of Fig. 2, after removal of the dead branches of the borders detected;

Fig. 4 is a block diagram of the method of the present invention;

Fig. 5 shows diagrammatic examples of relationships between the point of a detected border and the neighbouring points or clusters of points;

Fig. 6 shows an example of closed edges identified during the method of the present invention;

Fig. 7 shows an example of the stage of filling of the zones external to a closed edge, in order to identify a closed masking area.

The method of the present invention is adapted to work in combination with an electronic processor comprising a memory, a display unit or video screen, and an inputting device such as a keyboard, mouse, joystick or the like. The electronic processor is preferably, although in a non-limiting manner, connected to an image data acquisition device such as a scanner. The electronic processor is optionally connected to a data network or to a telephone line or the like.

A digital image comprises a plurality of points or pixels organised in successive rows, each of which is defined by a group of values stored in the memory of the electronic processor and identifying the colour characteristics of this point.

Known digital image acquisition devices (video cameras, digital cameras, colour scanners, etc.) generally encode each point of an image using a trio of values that expresses the level of the red, green and blue tones of the colour of the point (RGB code) which define the point's "colour coordinates". On the basis of this code, an algorithm for converting the colour coordinates of the point is applied and supplies as output a trio of values expressing the level of chromatic hue, luminance and saturation of the colour of this point (HLS code). This conversion is useful for the purposes of the subsequent stage of the method of the present invention which consists in converting a digital colour image into a digital image in grey tones, an example of which is shown in Fig. 1. Each point or pixel of the digital image 10 is associated with a data structure POINT containing the value POINT_VALUE which identifies only the relative luminance of the point. In the system of the present invention, therefore, in contrast to known systems, and despite the adaptation of the system for use in the colour management sector, the information on chromatic hue present in the original image is substantially disregarded or reduced solely to the level of luminance gradation.

The luminance data of the points of the digital image, stored in the field POINT_VALUE, are processed by an edge-detection algorithm implemented in the form of software on the electronic processor. A wide range of algorithms adapted for this purpose are known, whose description lies outside the scope of the present invention, which supply as output, for each point of the digital image, a

value representative of the luminance gradient of the neighbouring points. For the purposes of this description, without this being considered limiting, it will conventionally be assumed that this value is the higher, the more abrupt the luminance variation between the point in question and its neighbouring points, i.e. the higher the luminance gradient.

If the value of the luminance gradient of a certain point is high and exceeds a predetermined threshold value, this point is considered to be a border between zones of different luminance, which could be the border separating an object depicted in the digital image and the background or the border between two objects. The best edge-detection algorithms for the purposes of the present invention supply as output borders of a width substantially equal to a point or pixel, so as to define a map of substantially elongate and linear borders.

If the value of the luminance gradient in a point exceeds the above-mentioned threshold, this point is conventionally considered to be "black" and, for simplicity of explanation, will be referred to in the following description as a "border" point. In contrast, those points in which the above-mentioned value of the luminance gradient does not exceed the above-mentioned threshold value are conventionally defined as "white". At the end of the edge-detection algorithm, the data stored in POINT_VALUE contain the values of the luminance gradients of the various points of the image. These values are then interpreted as "black" or "white" (or in an equivalent manner as "true" or "false") values, by comparing them with the above-mentioned threshold value.

These values of white (false) and black (true) points are successively considered during a closure cycle, repeated one or more times, and in turn comprising a first stage of edge labelling (LabelEdges), a second stage of scanning to close (ScanToClose) and a third stage of definition of the neighbouring points (SetRealNeighbours). In more detail, during the stage of edge labelling, each point is considered on the basis of the intensity of the luminance gradient detected, in particular on the basis of whether it is black or white, in practice by reading the value of the datum POINT_VALUE. During this stage, a vector of data structures

BORDER is generated, and is stored on the processor separately from the vector of structures POINT of the point data, in which those borders that show continuity, i.e. that have one or more neighbours, wherein a neighbour is understood as an adjacent "black" point or cluster of "black" points, are progressively listed. Each border is identified by a label BORDER_LABEL, in practice a progressive numerical value, and a length value BORDER_LENGTH, equal to the number of points or pixels from which the linear development of this border is composed, is assigned thereto. In a variant of the present invention, each border is also assigned a coherence value BORDER_COHERENCE, indicative of the regularity of the border which will, for instance, be the higher, the more the border is regular, and the lower, the more the border is disjointed or irregular. During the labelling stage LabelEdges, all the borders, whether closed or open, and of whatever length, are in practice identified, provided that at least one point of the border has a sufficiently significant gradient, i.e. above the predetermined threshold value.

Each point of the image is thus associated, in addition to the value POINT_VALUE, with a further label value POINT_LABEL which can assume the values LABEL_NONE (when the point is white and does not belong to any identified border), LABEL_BOUNDARY (when the point is located on the edge of the digital image), or a label value corresponding to the progressive identification list of the corresponding border as identified by the value BORDER_LABEL in the manner described above.

In the subsequent stage of scanning to close, it is attempted to close the incomplete borders to generate closed edges, by adding "black" points to the map of points processed by the edge-detection algorithm. Fig. 2 shows an example of the image obtained from the image 10 of Fig. 1, displaying the borders obtained at the end of the stage of scanning to close. In particular, use is made for this purpose of the border length value BORDER_LENGTH identified in the preceding labelling stage LabelEdge. A fairly rapid method consists in seeking to prolong a border only if its value BORDER_LENGTH is sufficiently long and higher than a threshold value that can be predetermined or determined on the basis of the mean of the length of borders identified and stored in the structures BORDER. Starting

from an open end of one these open borders, a search is carried out among the surrounding points to identify a further black point, and thus to prolong the open end by adding intermediate black points. When considering these surrounding black points, points belonging to the same border to which the same end point in question also belongs are disregarded, in order to avoid closing the border on itself.

The distance in points or pixels to which reference is made when searching for another border from the end of an open border is proportional to the value of the length of the latter (BORDER_LENGTH), so as to avoid prolonging very short and often incidental fragments and to promote the closure of borders whose linear extension is of particular significance. During this stage, the choice of the path of closure of the open border, i.e. of the sequence of "white" points to be converted into "black" points, can be optimised in various ways. For instance, account could initially be taken of all the points that lie on the most direct trajectory or on the shortest path that joins the end of the open border to the target border. As an alternative, or in combination, account can be taken of the actual value of the luminance gradient of the adjacent points, even though these have initially been considered as "white" points. This means that the various possible trajectories for joining the end of the open border with the target border include those containing points whose luminance gradient is slightly below the threshold separating the black points from the white points, but nevertheless greater than that of all the other surrounding points not belonging to the open border. For practical purposes, it is enough temporarily and locally to lower the threshold value of the luminance gradient in order to cause any further "black" points that can be used as an indication of the best path to be followed to close the open border to "emerge" from the cluster of "white" points adjacent to the end of the open border. In addition or as an alternative to the criteria for choosing the above-described closure path, account can be taken of the coherence value BORDER_COHERENCE in order to identify a border closure path that is most in keeping with the morphological characteristics of this border.

At the end of each repetition of the stage of scanning to close CloseToScan, the

stage of definition of the neighbouring points SetRealNeighbours defines (when first run) or updates (when subsequently run) a numerical value POINT_NEIGHBOURS representative of the number of clusters of black points bordering each black point P of the digital image. In particular, with reference to Fig. 5, this numerical value is:

0: when the black point P in question has no neighbouring black point and is therefore an isolated point in the map M of the image, not belonging to any border (example 5a);

1: when the black point P in question is the end point of a branch of open border (example 5b);

2: when the black point P in question is a point belonging to a generic border (example 5c);

3 or 4: when the black point P in question is the point of intersection of several branches of a border (example 5d).

Following the stage of re-definition of the neighbouring points SetRealNeighbours, the data BORDER_LABEL and BORDER_LENGTH are updated, making further use of the above-mentioned stage of labelling of the borders LabelEdges, to reflect the fact that some borders have been combined to form closed edges in the preceding stage of scanning to close ScanToClose.

The closure cycle comprising the three stages described above is repeated until it is no longer possible to close any edges. In practice, a maximum number of possible repetitions is set in order to prevent any risk of overly long processing times. Experimentally, it has been found that a maximum of twenty or so repetitions provides very acceptable closure results.

At the end of the closure cycle, the digital image has a series of closed edges and open branches, the latter being formed by the residual open borders that were too short or too distant from other borders to be closed in the closure cycle. Fig. 2 shows an example of the graphical representation of the resulting digital image. A successive stage of the system of the present invention consists in the pruning of

the open branches. For this purpose, account is taken of the ends of the borders or branches that have remained open despite the application of the closure cycle, and in particular of the black points for which the value POINT_NEIGHBOURS is equal to unity. From the end of each open branch and proceeding backwards along this branch, pruning takes place by decreasing the value POINT_NEIGHBOURS of each black point of the open branch by one unit, until an intersection, for which the value of POINT_NEIGHBOURS, although decreased by one unit, still remains above one, is encountered. In practice, the starting point is the end of an open or dead branch where the value of POINT_NEIGHBOURS decreases from one to zero. The adjacent black point is then evaluated, decreasing the value of POINT_NEIGHBOURS by one unit for this point as well. There are two possibilities at this point: if the new value of POINT_NEIGHBOURS is equal to unity, then this black point is the new end of the open branch and its corresponding adjacent black point is then considered, or the new value of POINT_NEIGHBOURS is greater than unity and the pruning procedure is then discontinued because an intersection has been encountered.

At the end of a pruning operation, all the points of a dead branch will have a POINT_NEIGHBOURS value equal to zero, apart from the "node" point, i.e. the black point located at the intersection of the dead branch with another branch or edge. In practice, at the end of the pruning operation, all the points of the digital image belonging to closed edges will have a POINT_NEIGHBOURS value equal to or greater than two. For the successive stages of the method it is sufficient therefore to take account solely of the POINT_NEIGHBOURS value of each point.

The method described up to now is intended to identify closed edges of non-negligible length and to label them, making it possible to start from the map of borders detected by the edge-detection algorithm (Fig. 2) in order to close any edges that are open as a result of small discontinuities that cannot be detected from the original digital image (Fig. 1), eliminating the open branches that have not been closed (Fig. 3).

Some areas, albeit only edges closed one or more times, have not, however, been

identified. As shown in Fig. 6, the method up to this point has labelled as closed edges both simple edges 6a and the edges 6b and 6c which are also closed but more complex. This latter type of closed edge 6c is defined as a "lens edge" and comprises a border whose ends are closed on themselves to form two "lenses" or eyes, connected together by the intermediate section of the border. These lens edges are problematic and often impede the elimination of borders that do not define closed edges from the data of an image. It is therefore preferable to carry out a stage of elimination of lens edges in order to try to remove spurious elements from the digital image data.

The stage of elimination of the lens edges is in practice indispensable when, for the construction of masks, use is made of known methods for the construction of polygons from ordered series of points. By definition, these polygons are bounded by closed edges. In this case, unless the edges are completely eliminated, the results of the final masking will be unpredictable and incorrect. In the preferred embodiment of the invention, however, as specified in detail below, it is not strictly necessary to remove the lens edges, since the masking of the digital image can be carried out by means of a stage of definition of simple closed areas, without the need to order the points of the closed edges that bound them.

In the stage of elimination of the lens edges it is possible to prune the intermediate section that unites the two end eyes, or to assimilate each end eye with the end of an open border, which is closed in a manner substantially similar to that described with reference to the cycle of closure of open borders. The choice of the type of method to be used to eliminate the lens edges depends to a large extent on the length of the intermediate section related to the length of the end eyes. Advantageously, the stage of elimination of the lens edges may be included within the closure cycle as described above, prior to the pruning stage, so as also to take account of the borders that have a single end eye, of small dimension, that can be assimilated with the end of an open border.

At the end of the cycle of closure, pruning and possible elimination of lens edges, the masking data are collected in the form of an object vector, each of which contains the data relating to an individual closed edge that has been detected, in

particular the value of its length BORDER_LENGTH and the list of the points belonging thereto, on the basis of the labelling of these points by means of the value POINT_LABEL. The digital image is scanned according to a sequence from the top-left to the bottom-right in order always securely to find, in the succession of closed edges, an outer edge (container) before a corresponding edge contained therein. This method consists in listing the various closed edges in an ordered sequence. The individual points belonging to the various edges are not collected, however, in any particular order, since this not essential for the purposes of the present invention and makes it possible to speed up the masking method.

Subsequently, the points of each edge, taken in an ordered manner from the ordered sequence of edges obtained from the top-left to bottom-right scanning as described above, are added individually to a temporary auxiliary map. In this map, each point or pixel is coloured, for instance in white or black, or in two other distinct colours, depending on the "black" or "white" value of the value POINT_VALUE determined in the previous stages. A successive operation to fill the zone external to the edges with a colour different from the first two colours makes it possible immediately to identify the area inside and the area outside the edge which defines the broadest perimeter of the figure. This stage is shown in diagram form in Fig. 7, in which 7a shows an auxiliary map M1 to which the points of a closed edge B have been added. Fig. 7b shows a an intermediate stage of the operation to fill the zone E external to the closed edge B, and Fig. 7c shows the resulting masking area K identified by the filling operation. The filling stage is repeated for each closed edge identified in the previous stages, thereby identifying a sequence of closed areas.

The individual closed areas identified on the temporary map are input into a common map, in their original position, with reference to the position data of the points of the original digital image. The areas are input into the common map in the order defined by the ordered sequence of edges identified by the top-left to bottom-right scanning, so as to be able simply to verify whether any one of their points matches, i.e. coincides with, an internal point of an area defined by a previous edge in the above-mentioned sequential order. It is thus possible simply

to verify whether each area is or is not contained within other closed areas previously input into the common map, thereby making it possible to organise these areas according to a hierarchy of container-contained areas, for instance to manage any holes in the masks. For instance, the outermost areas can be considered to be full, while the successive areas in the container-contained hierarchy, the so-called "daughter" areas, can be considered as holes in the areas higher up the hierarchy, which are thus "emptied" in the zone occupied by the daughter area that they contain. In the example of Fig. 3, the closed edge 13 defines the inner area of the frame 11 of the window shown in the image of Fig. 1, while the closed edges 14 define holes in this frame 11, corresponding to the glass panes 12 of the window of Fig. 1. The method of the present invention thus makes it possible to achieve the objective of defining in a simple and rapid manner, without intervention by the user, a mask for the object formed by the frame 11 of the window depicted in the image of Fig. 1.

At this point, the user may for instance select a colour at will from the database stored on the electronic processor and apply this colour to the mask defining the frame 11 in order to change, on the original colour image, only the chromatic hue of this frame. Moreover, the luminance data of the points of the original image are still available, so that the luminance parameter of the new colour selected by the user may be graduated, point by point, within the mask of the frame 11, in order to obtain a very realistic colouring effect of the digital image that respects the light and shade contrasts of the real subject as originally photographed.

The above-described procedure, which is fully automatic, may be integrated with a stage of interactive modification guided by the user. Depending on the characteristics of the original image, for instance, the border closure cycle could have generated closed edges surplus to actual requirements, for instance the closed edge 15 of Fig. 3. It is sufficient to provide a device for modifying the borders that works on the map of borders of Fig. 3, guided by the inputting device, for instance a mouse. By using this device of an "eraser" type it is possible to cancel some points of the closed edge 15 to convert it into an open border. Subsequent transition through the automatic pruning stage will eliminate the edge

15 which the user has changed into an open border.

In contrast, the border map of Fig. 2, obtained at the end of the closure cycle prior to the pruning stage may be displayed to a user who wishes to close any borders that are still open. For this purpose use can be made of a device of the "stylus" type which makes it possible to draw lines of a width equal to a point or a pixel, blackening the points indicated by the user on the map by means of an interactive inputting device such as a mouse.

The stage of filling and definition of the hierarchy of closed areas may also be made interactive with a user. As shown in Fig. 7, the automatic filling procedure considers only the closed area surrounded by the most peripheral profile of an edge B closed several times. In the final mask K, the sub-areas K1, K2, K3 and K4 of example 7b are ignored. The masking map, for instance that shown by 7b in Fig. 7, may be displayed to a user who, by means of an inputting device, may indicate one of the points inside one of the sub-areas K1, K2, K3, K4 in order to fill its interior, aggregate it with the external area E and remove it from the closed masking area K.

Without prejudice to the principle of the invention, its embodiments and details of construction may be widely varied with respect to those described and illustrated without thereby departing from the scope of the present invention.